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Wind and Earthquake Mitigation: The Impact of Dampers on Tall Structures

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Abstract

This paper provides an in-depth examination of the effects of both earthquake and wind loading on high-rise buildings situated across various terrain categories and seismic zones. The research underscores the critical importance of accounting for lateral loads in the design of reinforced concrete structures, as this consideration is essential for maintaining structural stability and ensuring the safety of occupants. The study focuses on identifying the critical design loads for multistory buildings subjected to varying wind speeds, specifically 39 m/s and 50 m/s, as well as seismic forces corresponding to seismic Zones II and V. The analysis is conducted in strict adherence to the IS 1893:2002 code for earthquake loads and the IS 875:2015 code for wind loads, ensuring compliance with established safety standards. By meticulously evaluating the response of high-rise buildings under these diverse conditions, the study aims to identify the predominant design loads that should be prioritized for structures located in specific wind and seismic zones. The findings reveal that high-rise buildings are significantly influenced by both wind and seismic forces, with the results indicating that wind forces can impact high-rise structures in a manner comparable to seismic forces. This highlights the necessity for a comprehensive and integrated design approach that accounts for both types of loads to achieve optimal structural performance and safety. The research contributes valuable insights into the complex interplay between wind and seismic forces, emphasizing the need for careful consideration of both in the structural design of high-rise buildings.

Keywords: High-rise building, wind loading, fluid viscous damper, terrain, seismic zones

INTRODUCTION

In general, for design of tall buildings, both wind as well as earthquake loads need to be considered. Dynamic analysis is essential for structures with specific features such as height, seismic zone classification, and structural irregularities, including soft and weak stories. This study focuses on analyzing a G+20 multistoried residential reinforced cement concrete (RCC) building to assess its response to earthquake and wind loads using relevant Indian Standard codes [1, 2].

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The initial phase involves evaluating the base shear sensitivity of the building based on its location in different wind zones across India. Calculations of wind and earthquake loads are performed for various regions, including Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh, the Central Himalayas, north and central Bihar, the northeast Indian region, the Rann of Kutch, and the Andaman and Nicobar Islands [3, 4].

Terrain categories are crucial for determining a structure's wind exposure, with different terrains producing varying roughness effects. Rougher terrains are more effective at slowing down wind within the atmospheric boundary layer. Member forces are calculated using the load combination limit state method, and members are designed for the most critical forces. The building is subjected to self-weight, dead load, and live load according to the relevant standards [5, 6].

The structure's safety is checked against prescribed limits for base shear, joint displacement, interstory drift, and acceleration, considering the effects of both earthquake and wind loads on buildings.

Theoretical Background

Lateral Loads in Structural Design

Lateral loads, such as wind and seismic forces, are significant factors in the design of high-rise buildings. These forces can induce considerable stress and deformation, impacting the structural integrity and safety of buildings. Reinforced concrete structures must be designed to withstand these lateral loads to prevent catastrophic failures during events such as earthquakes or strong winds [7].

Wind Loads

Several factors influence wind loads on buildings, including wind speed, building height, and the roughness of the surrounding terrain. The IS 875:2015 code provides guidelines for calculating wind loads on structures, taking into account different terrain categories and wind speeds. Wind pressure on a building's surface varies with height and exposure, requiring detailed analysis to ensure adequate structural support [8].

Earthquake Loads

Seismic forces are a result of ground motion during an earthquake. The IS 1893:2002 code outlines the procedures for determining earthquake loads on structures. These loads depend on several factors, including the building's location within different seismic zones, soil type, and the structure's dynamic characteristics. Seismic loads induce both lateral and vertical forces, necessitating a comprehensive design approach to ensure stability and safety [9].

Combined Load Effects

High-rise buildings in areas susceptible to both high winds and seismic activity need to be designed to handle the combined impact of these forces. The interaction between wind and earthquake loads produces complex stress patterns within the structure, necessitating advanced analysis and design methods. The design must guarantee that the building can withstand both types of loads at the same time, ensuring its structural integrity remains uncompromised [10].

Methodology

The present study analyzes the response of high-rise buildings under wind and earthquake loads using the IS 1893:2002 and IS 875:2015 codes. The buildings are evaluated for different wind speeds (39 m/s and 50 m/s) and seismic zones (II and V) to determine the critical design loads. The analysis includes the following steps:

1. *Modeling the structure:* High-rise buildings are modeled using advanced structural analysis software, incorporating material properties, geometric configurations, and load conditions.
2. *Load application*: Wind and earthquake loads are applied to the models according to the respective codes. The wind loads are calculated based on the terrain category and building height, while seismic loads are determined using the building's seismic zone and dynamic properties.
3. *Response analysis*: The structural response, including lateral displacement, base shear, and stress distribution, is analyzed under the applied loads. The analysis helps identify critical load combinations and their impact on the building's stability.
4. *Comparison of effects*: The effects of wind and earthquake loads are compared to determine the dominant loading conditions for high-rise buildings in different regions. The study evaluates whether wind or seismic forces govern the design in various scenarios.

MODEL DESCRIPTION AND ANALYSIS

Seismic analysis of structures is performed by considering lateral forces in conjunction with gravity loads. In this project, seismic evaluation of the existing residential building is conducted for various seismic zones using the equivalent static analysis method with ETABS software, as demonstrated in Tables 1 and 2 [11, 12].

Table 1. Structural properties used for building.

Property	Value
Number of stories	G + 20
Floor to floor height	3.2 m
Plinth height	0.8 m
Size of column	0.8 × 0.7 m
Size of beam	0.65 × 0.5 m
Earthquake load	As per IS:1893:2002
Slab thickness	0.15 m
Wall thickness	0.23 m
Live load including floor finishes	3.5 kN/m^2
Floor finishes	As per IS:part-1
Seismic zones	All five seismic zones of India
Type of soil taken	Hardy rocky
Safe bearing capacity (SBC) of soil taken	200 kN/m^2

Table 2. Material properties.

Material Properties	
Grade of concrete	M25
E of concrete	27.386 kN/m^2
Poisson's ratio of concrete	0.15
Coefficient of thermal expansion of concrete	1.70E-01
Coefficient of thermal expansion of steel	3.00E-01
Density of reinforced concrete	25 kN/m^2
Grade of reinforcing steel	Fe415
E of steel	2.00E+05
Poisson's ratio of steel	0.286

Load Combinations

Structure is to be checked for the following load combinations as per IS: 1893

1. 1.5(DL+LL)
2. 1.2(DL+LL+WL)
3. 1.5(DL+WL)
4. (0.9DL+1.5WL)

DL = dead load, LL = live load, and WL = wind load.

Calculation of Loads

a. Dead load
   i. Self-weight of beams and columns- as per ETABS software
   ii. Load intensity on slab = 0.125 × 25 =3.125 kN/m^2 (assume 125 mm thick slab)
   iii. Floor finish = 0.5 kN/m^2 (IS 875 (Part 1):1987; total load on slab = 3.625 kN/m^2
   iv. Outer wall load intensity=0.23 × 3.3 × 20 = 15.18 kN/m
   v. Inner wall load intensity =0.115 × 3.3 × 20 = 7.59 kN/m
   vi. Parapet wall load intensity =0.23 × 1 × 20 =4.6 kN/m

b. Live Load
   Live load on floors = 3 kN/m^2 (as per IS: 875 (Part 2):1987)

c. Wind Load
   [as per IS: 875 (Part 3):1987 and IS: 875 (Part 3):2015]

RESULTS AND DISCUSSION

After analyzing all the building models for zones 2 and 5 and terrain categories 2 and 4 as per method suggested by IS Code and studying graphs plotted for various parameters, comparison are made between zones and terrain categories.

The findings reveal that both wind and earthquake forces significantly impact the structural behavior of high-rise buildings. The results show that in some cases, wind forces can be as critical as seismic forces, particularly in regions with high wind speeds. The comparison highlights the necessity of considering both types of loads in the design process to ensure comprehensive structural safety [13].

The study emphasizes the need for robust design practices that account for the combined effects of wind and earthquake loads. By integrating both considerations into the design process, engineers can enhance the resilience of high-rise buildings, ensuring their safety and stability in regions susceptible to these forces [14].

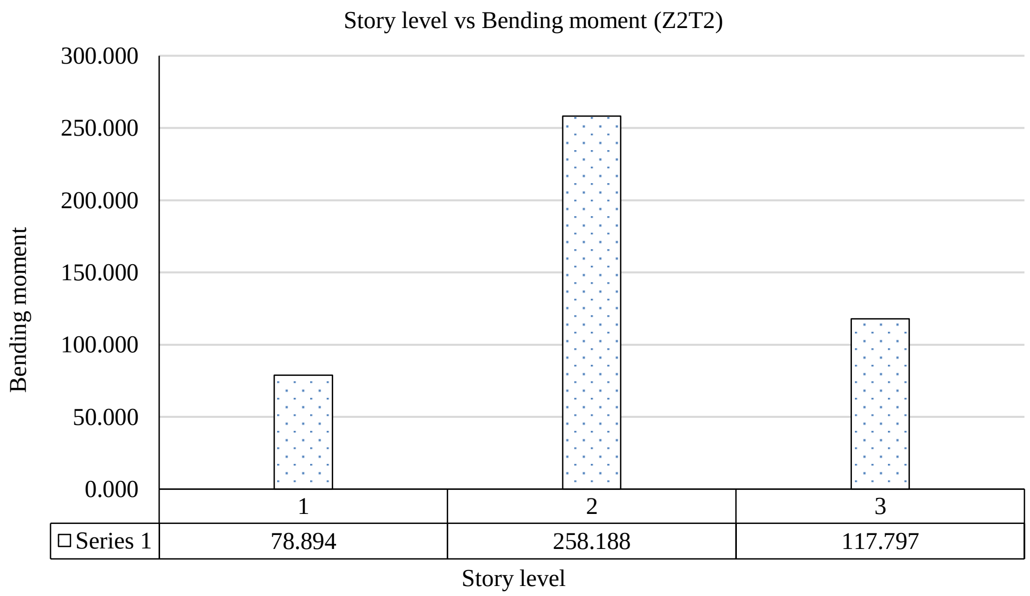
In conclusion, this research underscores the importance of a holistic approach to structural design, incorporating both wind and earthquake load considerations. This approach will lead to the development of safer and more resilient high-rise buildings capable of withstanding the combined effects of these forces (Figures 1–5 and Tables 3–8).

Table 3. Story level versus bending moment (Z2T2 and Z2T4).

	With Damper			Without Damper		
Story level	***Z2T2***	***Z2T4***	***Difference***	***Z2T2***	***Z2T4***	***Difference***
1	159.33	162.57	1.257	160.585	165.215	2.647
10	210.82	215.59	5.443	216.26	218.356	2.767
20	198.82	201.66	2.342	201.16	203.258	1.600

Table 4. Story level versus bending moment (Z5T5 and Z5T4).

	With Damper			Without Damper		
Story level	***Z5T2***	***Z5T4***	***Difference***	***Z5T2***	***Z5T4***	***Difference***
1	195.16	194.26	1.805	196.96	195.689	1.431
10	210.82	210.26	2.554	213.37	213.258	2.9944
20	198.82	198.82	1.08	199.9	199.912	1.096



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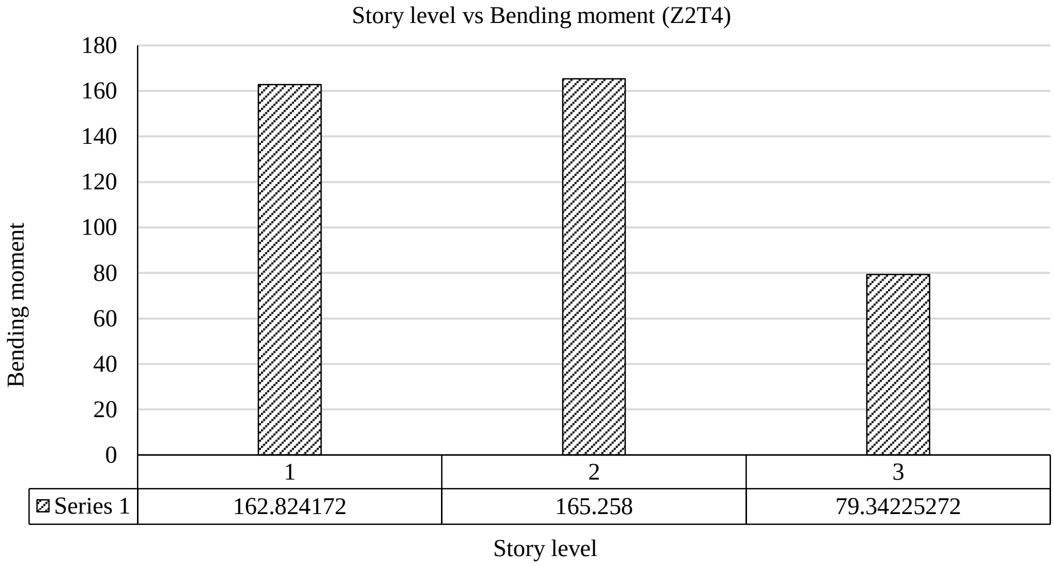
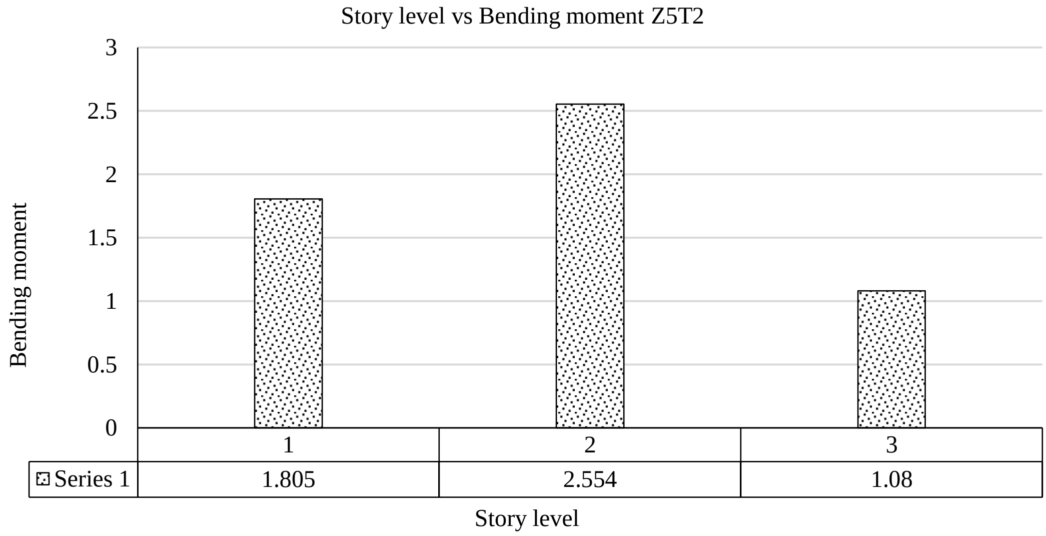


(b)

Figure 1. Story level versus bending moment for Z2T2 and Z2T4 with and without damper.



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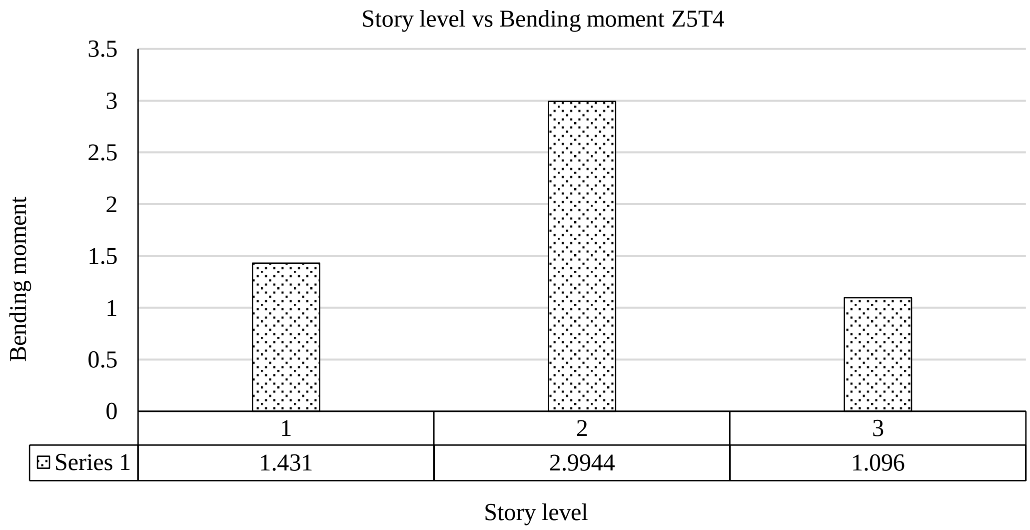


(b)

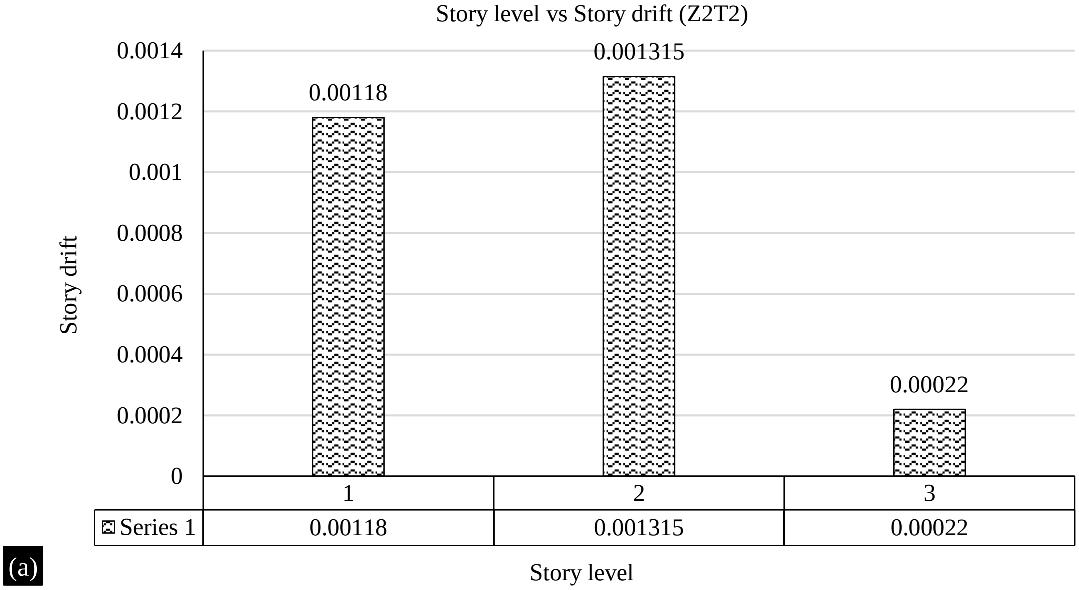
Figure 2. Story level versus bending moment for Z5T2 and Z5T4 with and without damper.

Table 5. Story level versus story drift (Z2T2 and Z2T4).

	With Damper			Without Damper		
Story level	***Z2T2***	***Z2T4***	***Difference (Z2T2)***	***Z2T2***	***Z2T4***	***Difference (Z2T4)***
1	0.002662	0.001392	0.00118	0.003842	0.001842	0.00045
10	0.002662	0.002788	0.001315	0.003977	0.004177	0.001389
20	0.001637	0.001817	0.00022	0.001857	0.001957	0.00014

Table 6. Story level versus story drift (Z5T2 and Z5T4).

	With Damper			Without Damper		
Story level	***Z5T2***	***Z5T4***	***Difference***	***Z5T2***	***Z5T4***	***Difference***
1	0.001392	0.001392	0.00045	0.001842	0.001557	0.000165
10	0.002788	0.002788	0.001389	0.004177	0.004177	0.001389
20	0.001817	0.001817	0.00024	0.002057	0.002157	0.00034



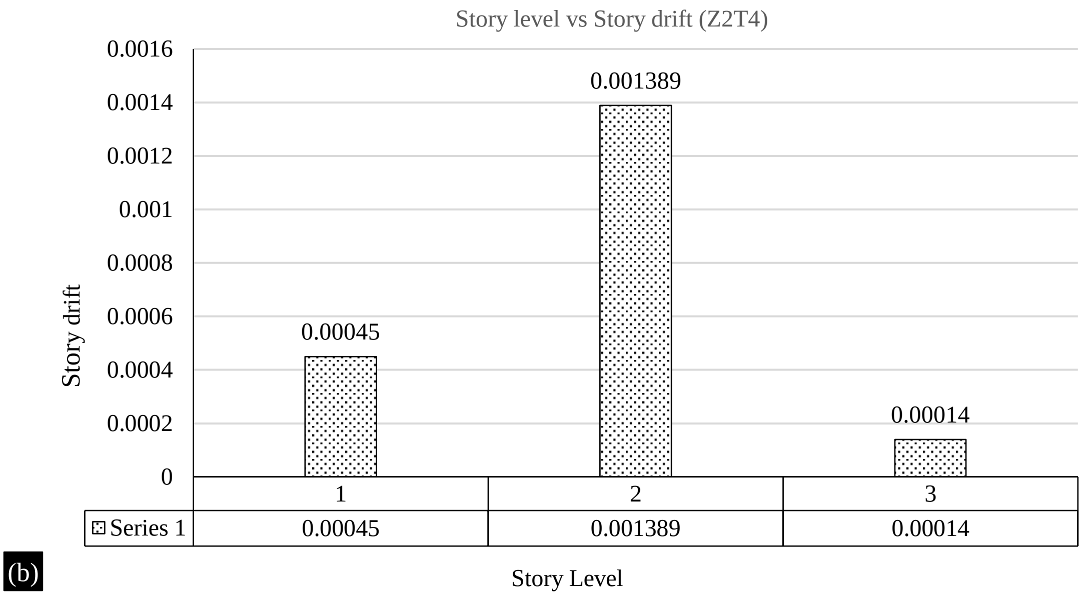
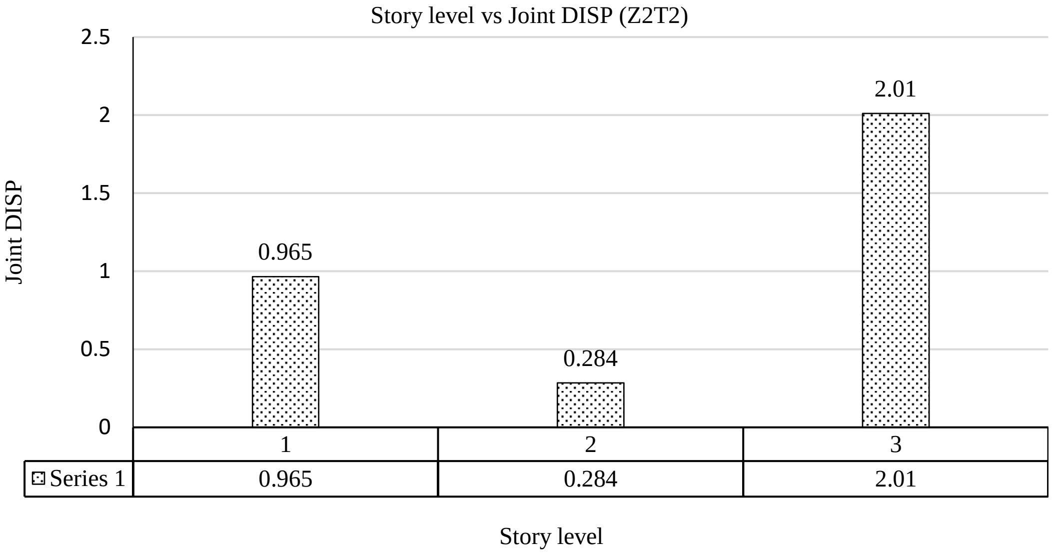


Figure 3. Story level versus story drift for Z2T2 and Z2T4 with and without damper.



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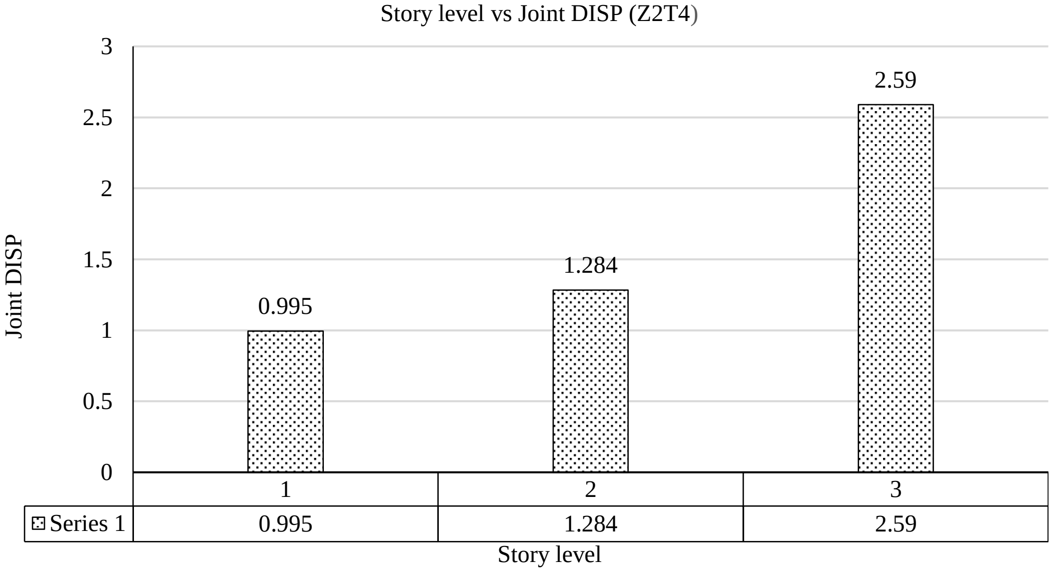

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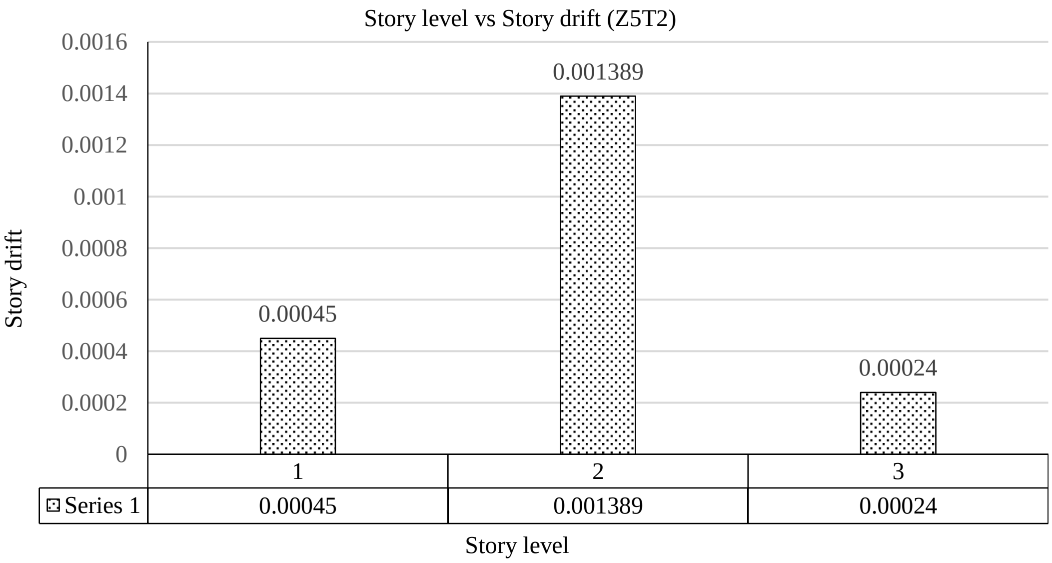
Figure 4. Story level versus story drift for Z5T2 and Z2T4 with and without damper.



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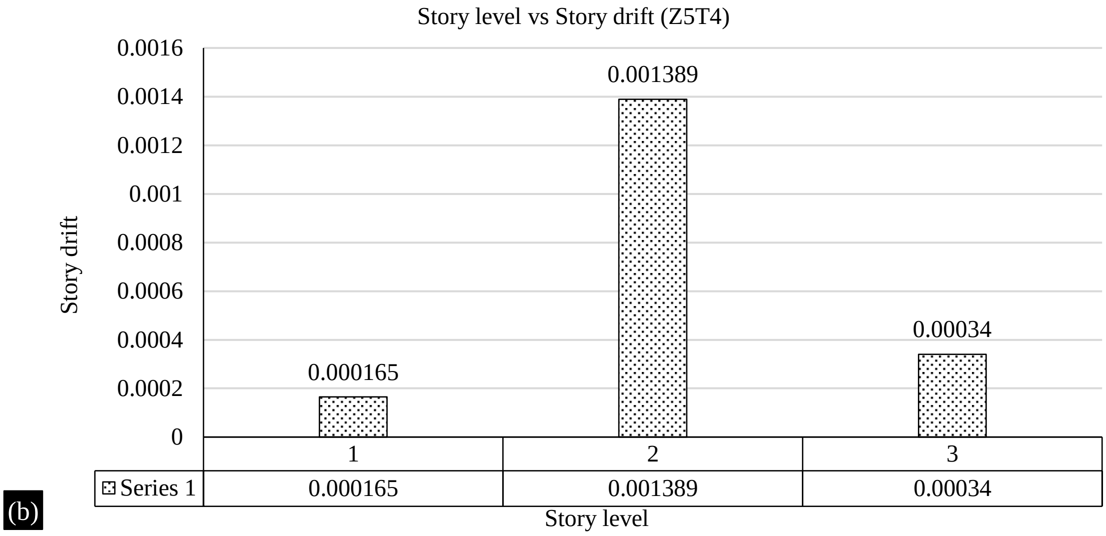

Figure 5. Story level versus story drift for Z5T2 and Z5T4 with and without damper.

Table 7. Story level versus story displacement (Z2T2 and Z2T4).

	With Damper			**Without Damper**		
Story level	***Z2T2***	***Z2T4***	***Difference***	***Z2T2***	***Z2T4***	***Difference***
1	6.885	6.855	0.965	7.85	7.85	0.995
10	92.972	92.972	0.284	93.256	94.256	1.284
20	126.359	126.068	2.01	128.369	128.658	2.59

Table 8. Story level versus story displacement (Z5T2 and Z5T4).

	With Damper			**Without Damper**		
Story level	***Z5T2***	***Z5T4***	***Difference***	***Z5T2***	***Z5T4***	***Difference***
1	6.885	6.885	0.965	7.85	7.85	0.965
10	92.972	92.972	0.284	93.256	95.36	2.388
20	126.068	126.068	3.292	129.36	128.369	2.301

CONCLUSIONS

In summary, designing high-rise buildings in regions susceptible to both strong winds and seismic activity necessitates a thorough understanding of how these lateral loads impact the structures. By considering wind and earthquake forces independently and incorporating robust lateral load-resisting systems, engineers can enhance the safety and stability of these structures. This approach ensures that high-rise buildings can withstand the combined impacts of wind and seismic events, leading to more resilient and economically productive structures.

1. The wind is acting on a structure like lateral load resisting system at the time of earthquake and ensure safety and integrity.
2. To make high-rise building more convenient, comfortable efficient, and economically productive.
3. The wind and earthquake effects increase rapidly when the height of the building increases.
4. Building should be designed in both directions independently considering the critical forces of wind or earthquake separately. The total shear force and the moment at the base result from seismic analysis when loads acting normal to the short side may be greater than the other direction.

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